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Variability in anatomical features of human clavicle: Its forensic anthropological and clinical significance

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ABSTRACT

Bones can reflect the basic framework of human body and may provide valuable information about the biological identity of the deceased. They, often, survive the morphological alterations, taphonomic destructions, decay/mutilation and decomposition insults. In-depth knowledge of variations in clavicular shape, size and its dimensions is very important from both clinical (fixation of clavicular fractures using external or inter-medullary devices, designing orthopedic fixation devices) as well as forensic anthropological perspectives. Human clavicle is the most frequently fractured bone of human skeleton, possessing high degree of variability in its anatomical, biomechanical and morphological features. Extended period of skeletal growth (up to third decade) in clavicle imparts it an additional advantage for forensic identification purposes. In present study, five categories of clavicular features like lengths, diameters, angles, indices and robustness were examined to explore the suitability of collarbone for forensic and clinical purposes. For this purpose, 263 pairs of adult clavicles (195 Males and 68 Females) were collected from autopsied cadavers and were studied for 13 anatomical features. Gender and occupational affiliations of cadavers were found to have significant influences on anatomical dimensions of their clavicles. Product index, weight and circumference of collarbone were found the best univariate variables, discriminating sex of more than 80% individuals. The best multivariate Function-I (*DF: -17.315 + 0.054 CL-L+0.196 CC-R+0.184 DM-L*) could identify sex and occupation of 89.4% (89.2% Male and 89.7% Female) and 65.4% individuals, respectively. All clavicular variables were found bilaterally asymmetric; left clavicles being significantly longer in length, lighter in weight, smooth in texture and less curved than the right side bones. Among non-metric traits, sub-clavian groove, nutrient foramina and 'type' of clavicle exhibited significant sexual dimorphism. Thus, both metric and non-metric features of clavicle can have decisive role in forensic identifications and clinical interventions. Present results would be of great significance for anatomists, orthopedicians, surgeons and the forensic anthropologists in their professional endeavors.

1. Introduction

The clavicle is the only horizontally placed long bone of the human skeleton which shows high variability in its shape and size; more frequently than other long bones of human skeleton [1]. The anatomical variability of this important bone of the anterior human thoracic skeleton has been widely explored by clinicians and forensic anthropologists. Its mean dimensions may be similar in unrelated races which are geographically separate, or it may be of different dimensions in related racial groups [2]. Much of the adult morphology of human clavicle (a double-curved S-shaped outline) is attained early in fetal life well before birth [3]. Males and females attain 80% of their total clavicle length by 12 and 9 years of age, respectively [4]. Clavicle has a longer period of skeletal growth during which it may respond to a variety of mechanical loadings and shear stresses. Variations in mechanical forces, asymmetric vascularization, lateralized behavior, activity-induced changes or more stress loadings of the dominant hand side of the clavicle may be factors responsible for asymmetrization of various clavicular features [5], among others.

Murphy [6] and Králik et al. [7] reported that later-maturing skeletal elements (like clavicle) display a greater degree of sexual

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dimorphism and bilateral asymmetry than the early-maturing skeletal districts due to the fact that physical activity and work distribution an individual may influence clavicular morphology [8]. Auerbach and Raxter [9] have reported that activity patterns of an individual, mechanical behavior and unique developmental pathway of clavicle may significantly contribute to its atypical asymmetric pattern and varied diaphyseal breadths; the latter being more sensitive to the effects of loadings than the lengths. Clavicle has been found thicker and more curved in manual workers [10–12]. Clavicle possesses sex-, side-, activity-, laterality- and occupation-dependent osteological variations in its features and; these factors need to be considered while carrying out forensic anthropological or clinical (orthopedic or anatomical) examinations using this bone. Clavicle has an additional forensic advantage of being having extended growth period sufficient to indent additional identifying features in it. Its physical dimensions (metric) and characteristic appearance (non-metric) are useful for forensic identifications, particularly in age and sex estimations of unknown skeletal remains [12,13]. Though some previous studies have reported significant sex and age-dependent variations in its features [7,12,14–20], it still remains underrepresented in literature as a potential estimator of identity of an unknown skeleton [12,19].

In-depth knowledge of variations in clavicular anatomical features has been found essential for inter-medullary fixation of clavicular fractures and designing orthopedic fixation devices [21,22]. Significant shortening or asymmetry of clavicle in skeletally mature adults can affect clinical/surgical treatment strategies [20]. In traumatic settings, clavicle is found as the most commonly fractured bone of human skeleton (being about 4% of total skeleton and 35–45% of shoulder girdle fractures). It gets commonly fractured at its middle third portion (80%) followed by lateral third (10–18%) and medial third (2–10%) portion, particularly in adults and children [21]. Most often such fractures are managed non-operatively [23] by orthopedicians or bone-settlers. Pre- and post-operative complications of clavicle fixations can be better understood and prevented by having detailed information of complex anatomical and biomechanical features (like dimensions, diameters, curvatures, angles, robusticity etc.) of this bone. Increased rates of non-unions and more demands for use of nail and plate fixative devices for treating clavicular fractures have necessitated some extensive studies based on examination of its anatomical and morphological features. Present forensic anthropological study was conducted on the clavicles collected from medico-legal autopsies of Northwest Indian subjects with the following objectives:

- To estimate mean value of various anatomical dimensions of clavicle.
- To assess degree of sexual dimorphism, bilateral asymmetry and activity-pattern specific variations in the clavicle
- To highlight inter-disciplinary significance, if any, of various morphometric and non-metric features of clavicle.

2. Materials and methods

Present study is based on osteometric and morphological analysis of 263 pairs of clavicles collected from 195 male and 68 female adult cadavers (17–94 years) whose post-mortem examinations were carried out at the Department of Forensic Medicine, Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh, India. The research proposal for present study was ethically approved by the Institutional Ethics Committee, and a well-informed written consent was obtained from relatives of each deceased before starting bone collection and examination. Indian population has been classified into various distinctive heterogeneous groups, clustered together on the basis of their similarity in morphological, environmental (nutrition, climate, food habit) and genetic features [24–28]. The studied population group is heterogeneous one having individuals from five North-western Indian states of Punjab, Haryana, Himachal Pradesh, Uttar Pradesh and Chandigarh. Cadavers from other states were ignored for bone collection to avoid any distortion in the clavicular dimensions as people from different Indian zones have different body sizes and dimensions, skeletal proportions and measurements (10, 15–16). Clavicles were also arbitrarily classified into two groups of strenuous and non-strenuous workers depending upon occupational activity patterns of the deceased. Clavicles were collected only from right-handed cadavers and their handedness was inquired about from the relatives.

Both clavicles and the sternum were removed as a single piece during routine post-mortem procedures by giving incisions at the acromio-clavicular, sterno-olecranon and costo-sternal junctions along a standard linear midline incision [29]. Clavicle was removed from the sternum and then boiled, cleaned, washed, dried and prepared for taking measurements using standard detergent maceration protocol [30]. The left-over attached soft tissue, if any, were removed manually with the help of blunt scalpels. The bone/s showing any malformation, fracture, surgical treatment or abnormal anatomy etc., were removed from final analyses. Both clavicles were replaced into the dead body before handing over it to the claimant relatives. Each measurement was taken three times; their average was recorded as the mean value of the parameter. All the measurements were taken by the first author and intra-observer errors were calculated for different variables. Great care was taken while recording measurements on the clavicle as a small change in its orientation can introduce large differences in its dimensions, thus affecting the accuracy, precision and reproducibility of analyses. The outline/contour of each clavicle was drawn on a paper sheet (with its anterior and posterior borders in the same horizontal plane) after taking measurements. The medial and lateral angles were measured with protractor; and two curvature depths were estimated with a foot ruler on the outlined figure of the bone. A brief description of various clavicular measurements has been diagrammatically represented in Fig. 1 and explained as below:

2.1. Metric measurements

2.1.1. Dimensions

(i) Clavicular length (CL): It is measured as the maximum distance between the outermost tips of the sternal and acromial ends of clavicle placed on an osteometric board (ignoring curves of the bone) accurate to within 0.5 mm [12,19,31,32].

(ii) Articular Length of Clavicle (AL): It is the straight distance between the mid-points of the sternal and acromial articular ends of clavicle measured with the help of a spreading caliper with pointed ends, accurate to within 0.5 mm as per the technique used by Parsons [14].

(iii) Mid-point Circumference (CC): The midpoint of clavicular shaft is marked between acromial and sternal ends of clavicle placed in anatomical position on the osteometric board and circumference is measured at this point with a strip of graph paper marked in millimeters, accurate to be within 0.5 mm [12,19,31,32].

(iv) Weight of Clavicle (WC): The completely cleaned, dried but still wet clavicles were weighed with the help of an electronic weighing machine ("ΔIcoscl" EK-6000G, Bombay

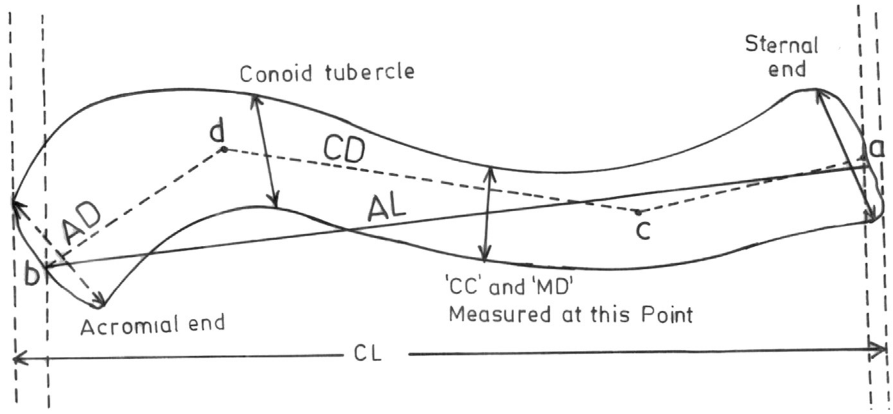

Fig. 1. Graphical representation of different clavicular measurements considered in present study.

Burmah Trading Corporation Limited) accurate to be within 0.5 g [33,34].

2.1.2. Indices

(v) Robusticity (RI) or robustness index: It is the robusticity measure of the clavicle and was calculated as a ratio of mid-circumference of clavicle to the clavicular length and, multiplied by 100 [12,16]:

$$\text{Robustness Index (RI)} = \frac{\text{Mid-point circumference (CC)}}{\text{Clavicle Length (CL)}} \times 100$$

(vi) Product-Index (PI): It is taken as the product of clavicular length and mid-point circumference of clavicle measured in millimeters [12]:

$$\text{Product Index (PI)} = \text{Maximum Clavicular Length (CL)}/\text{Mid} - \text{clavicular Circumference (CC)} \times 100$$

2.1.3. Diameters

(vii) Sternal Diameter (SD): It is the straight distance between the highest and lowest point of sternal articular surface in sagittal plane, measured with Mitotoyo's Digitmac vernier caliper accurate to be within 0.5 mm [7].

(viii) Acromial Diameter (AD): It is the straight distance between the highest and lowest point of acromial articular surface in sagittal plane, measured with Mitotoyo's Digitmac vernier caliper accurate to be within 0.5 mm [7,35].

(ix) Middle Diameter (MD): It is measured as a linear distance between anterior and posterior surfaces of clavicle diaphysis measured at mid-point (level of mid-circumference) using Mitutoyo Digitmac vernier caliper [7].

(x) Conoid Diameter (CD): It is measured as a linear distance between anterior and posterior surfaces of diaphysis measured at level of conoid tubercle in sagittal plane (near acromial end) using Mitutoyo Digitmac vernier caliper [7,35].

2.1.4. Angles

Different angles of the clavicle were measured on its outlined contour on a paper sheet. Each clavicle was placed on a drawing sheet in such a position that its anterior and posterior borders are in the same horizontal plane. The midpoints of medial and acromial ends were marked as ‘a’ and ‘b’, respectively. The central axis of the clavicle was drawn as a curved line, midway between the anterior and posterior borders throughout the length of the clavicle. The double curvature of the clavicle is visible in outlined contour with two distinct convexities; the medial two-thirds portion was convex anteriorly while the lateral one-third portion was posteriorly convexed [14]. The deepest points on the two curves of the clavicle where the convexities were the maximum, were marked as points ‘c’ and‘d’ and they were joined by a straight line. The points ‘c’ and ‘d’ were joined with midpoints ‘a’ and ‘b’ at the corresponding ends to form lines ‘ac’ and ‘bd’, thus forming two angles; a medial angle ‘acd’ which gave the curvature of medial two-thirds, and a lateral angle ‘bdc’ which represented the curvature of the lateral one-third. The sum of the two angles constituted the total curvature of clavicle [34,36].

(xi) Lateral Angle (LA): The angle ‘cdb’ which represent the curvature of the lateral one-third portion of clavicle was measured as lateral angle of clavicle with the help of a protractor

(xii) Medial Angle (MA): The angle ‘acd’ which represent the curvature of the medial two-third portion of clavicle was measured as the medial angle of clavicle with the help of a protractor

(xiii) Total Angle (TA): The sum of the above mentioned two angles (lateral and medial) constitutes the total angle of the clavicle [36].

Descriptive statistics like mean, standard deviation, SEE, variance etc., were calculated and discriminant function analyses were done by using IBM SPSS software version 21.0 [37].

2.2. Non-metric observations

Following five morphological traits of each clavicle were noted down:

2.2.1. Rhomboid fossa (RF)

It is a normal variant of the clavicle represented by a costal impression (depressed or pitted) on its inferior aspect; about 2–3 cm away from the sternal end where costo-clavicular ligament or rhomboid ligament connects the bone to the first rib. It is generally present in both sexes and may be of large, medium or small size. Arbitrarily, an approximate size of more than 25 mm along its long axis was considered as large, 15–25 mm as medium and less than 15 mm was taken as small [35–38].

2.2.2. Perforations (PF)

These are vascular openings present on postero-superior edge of the bone, at about mid-point or lateral third portion of clavicular shaft [35,38,39].

2.2.3. Nutrient foramen (NF)

It is a foramen present at the lateral end of the sub-clavian groove and is, generally, found located near the central half of the length of the bone. The presence, number and size of these foramina and their size were noted. Carroll [40] criterion was followed to estimate the size of the nutrient foramen, according to which if a foramina accepts a wire probe of 0.8 mm or more, it is a 'large' foramina. It was marked as 'medium' if a wire probe of diameter more than 0.5 but less than 0.8 mm was insertable in the foramina and was designated as 'small' if no wire probe of diameter greater than 0.2 mm [12] was acceptable by the pore in the bone.

2.2.4. Sub-clavian groove (SCG)

It is an obvious structure sharply defined on the inferior surface of the clavicle, starting from the medial end and then gradually deepening and becoming well defined laterally. If present, it may be large, medium or small, based on arbitrary visual observations [35,38,39].

2.2.5. Type of clavicle (TC)

The clavicle with a length of 140 mm or more was taken as 'long' and lesser than it was considered as 'small'; whereas the clavicle having robustness index of 25 or more was assumed to be 'robust' and less than this value was taken as 'smooth'. Thus, four different combinations of shape and size of the clavicle viz. short and smooth, short and robust, long and smooth or long and robust were noticed using this arbitrarily formed criterion.

2.3. Statistical analyses

The descriptive summary for different variables in two sexes is listed in Table 1. Independent *t*-test was applied to statistically compare the significance of differences in mean values between two sexes. Index of dimorphism (ID) was estimated for each variable by dividing male mean with female mean and multiplying it by 100 [18]. Univariate and multivariate (stepwise) discriminant function analysis (DFA) was applied to estimate the accuracy of sex and occupation estimations. Clavicle lengths, circumference, weight and diameters were used in Function-I. Total six combinations of variables were scrutinized in multivariate DFA (Function-I to VI). The percent directional asymmetries in different clavicular variables were calculated using the following formula [5]:

$$\% \text{ DA} = \frac{(\text{Right} - \text{Left})}{(\text{Right} + \text{Left})/2} \times 100$$

This formula gives both magnitude and direction of asymmetry. Asymmetry was also calculated as raw counts and their percentages, whether right measurement is greater, the left is greater or left and right are equal to each other. The number of cases and the percentage having greater directional asymmetry (either in left or right clavicles) was calculated for each sex and in the pooled data too. The percentage of clavicles showing no directional asymmetry (where right and left side clavicles are equal in dimensions) was also calculated.

3. Results

The average age of male and female cadavers was found as 38.5 and 36.0 years, respectively. Left clavicles were longer in length and more angulated than the right ones. Means of mid-circumference, weight, indices (RI and PI) and diameters (Except AD in males and CD in females) of the clavicle were found comparatively higher in right clavicles of both sexes. Length, product-index, weight and mid-circumference of clavicle had higher variability in their dimensions with comparatively greater standard errors of estimate (SEE) than other variables. Diameters at different anatomical points showed least right-left differences in clavicles of both sexes (Table 1).

Table 2 shows the results of paired *t*-test for comparing the mean values of various parameters in right and left-side clavicles and, the per cent directional asymmetry in various clavicular features. The results showed that all the variables (except acromial and conoid diameters in both sexes and only product-index in females) had significant bilateral differences in their means values. The negative (−ve) sign indicates that value is higher in left clavicles and vice versa. Except clavicular length, articular distance and angles; all other parameters had higher mean values in right clavicles. All clavicular variables exhibited right- or left-biased asymmetry in their metric features. The length, articular distance and all angles of clavicle displayed left-biased asymmetry in two sexes individually as well as in the pooled data, i.e., they were higher in left clavicles. Mid-circumference, weight and robusticity of clavicles were found statistically more in right-side clavicles. The male clavicles were distinctly asymmetric in their length, circumference, weight and lateral angle than the female clavicles. The reverse was true for sternal diameter in case of female clavicles.

Sexual dimorphism was distinctly present in almost all clavicle parameters, except angles. The mean values of clavicular length, circumference, indices and diameters were found statistically greater in males than the females. Female and left clavicles were comparatively more straightened than male and the right clavicles, respectively. Clavicle angles were found least sexually dimorphic; left angles had comparatively lesser sexual differences than the right ones. Right lateral and total angles were found significantly greater in females than the males. Index of dimorphism was found maximum for product-index and mid-point circumference and it was found minimum for clavicular angles. Product index was found as the most sexually dimorphic variable capable of discriminating sex of 85.9% (83.6% males, 92.6% females) subjects; followed by weight (82.5%) and circumference of clavicle (81%). Mid-diameter was comparatively more sexually dimorphic than the acromial or sternal diameters. The clavicular angles were found poorest sex discriminators (Table 1).

The stepwise multivariate DFA results using different combinations of studied variables can be found in Tables 3 and 4. The multivariate function using a combination lengths, circumference, weight and diameter (linear variables only) of clavicle was selected as the best function; discriminating sex of 89.4% subjects (89.2% males and 89.7% females). When diameters were not ignored from MVDFA of linear variables, accuracy rate slightly deceased to 87.5% (Function-II). The clavicular indices were able to identify sex of about 86% subjects (Function-VI). Thus, Function-I of all linear measurements was found the best and most reliable combination of variables for sex estimation from stepwise MDFA. Females were slightly better classified than males from various combinations of clavicular parameters considered in the present study. Table 4 shows that clavicular angles discriminated the physical activity or occupational activity patterns of the subjects more correctly, classifying 69.2% clavicles to the physical work category of their owner. Males were better identified from the combination of different

Table 1
Descriptive statistics of studied clavicle features with sexing accuracy level from univariate Discriminant function analysis.

Dimension	Variable	Side	Males (N = 195)		Females (N = 68)		*t*-test	ID	DFA sexing accuracy (%) (Male, Female)
			Mean ± SD	SEE	Mean ± SD	SEE			
Angles (degree)	LA	R	141.18 ± 1.81	0.13	142.56 ± 2.15	0.26	−4.73**	99.03	61.2 (59.5, 66.2)
		L	143.46 ± 1.72	0.12	143.96 ± 2.55	0.31	−1.50	99.65	
	MA	R	151.68 ± 1.70	0.12	152.00 ± 1.99	0.24	−1.20	99.79	NIL
		L	153.08 ± 1.63	0.17	153.38 ± 1.52	0.18	−1.36	99.80	
	TA	R	292.86 ± 2.59	0.18	294.56 ± 3.73	0.45	−3.49**	99.42	60.1 (60.0, 60.3)
		L	296.54 ± 2.54	0.18	297.34 ± 3.34	0.41	−1.79	99.73	
Lengths (mm)	CL	R	148.52 ± 8.88	0.64	135.22 ± 8.27	1.00	11.20**	109.84	77.9 (75.9, 83.8)
		L	151.87 ± 8.98	0.63	138.22 ± 8.30	1.00	11.43**	109.88	
	AL	R	143.6 ± 8.68	0.62	131.17 ± 7.75	0.94	10.60**	109.47	77.2 (76.9, 77.9)
		L	147.0 ± 9.01	0.64	134.19 ± 7.81	0.94	11.16**	109.56	
Circumference (mm)	CC	R	38.52 ± 3.28	0.24	32.66 ± 2.57	0.31	15.03**	117.94	81.0 (79.0, 86.8)
		L	37.24 ± 3.38	0.24	31.76 ± 2.70	0.33	13.46**	117.25	
Weight (gm)	WC	R	33.12 ± 5.73	0.41	23.09 ± 4.43	0.54	14.84**	143.44	82.5 (80.0, 89.7)
		L	31.95 ± 5.77	0.41	22.05 ± 4.51	0.54	14.42**	144.90	
Indices	RI	R	25.99 ± 2.36	0.17	24.20 ± 1.98	0.24	6.11**	107.40	64.3 (61.5, 72.1)
		L	24.58 ± 2.40	0.17	23.03 ± 2.02	0.25	5.17**	106.73	
	PI	R	57.29 ± 6.71	0.48	44.24 ± 5.14	0.62	16.58**	129.50	85.9 (83.6, 92.6)
		L	56.62 ± 6.50	0.48	43.98 ± 5.30	0.64	15.76**	128.74	
Diameters (mm)	AD	R	23.50 ± 3.46	0.25	20.71 ± 3.01	0.37	6.32**	113.47	66.5 (66.7, 66.2)
		L	23.76 ± 3.50	0.25	20.82 ± 3.26	0.40	6.27**	114.12	
	CD	R	17.02 ± 2.35	0.17	15.12 ± 2.30	0.28	5.82**	112.57	66.2 (63.1, 75.0)
		L	16.88 ± 2.44	0.18	15.05 ± 2.02	0.24	6.07**	112.16	
	MD	R	12.30 ± 1.53	0.11	10.17 ± 1.32	0.16	11.00**	120.94	76.8 (75.9, 79.4)
		L	12.00 ± 1.25	0.90	10.18 ± 1.11	0.13	11.37**	117.99	
	SD	R	22.09 ± 3.30	0.24	18.82 ± 2.72	0.33	7.34**	117.38	73.4 (75.9, 66.2)
		L	21.32 ± 2.93	0.21	18.12 ± 2.63	0.32	7.97**	117.66	

** differences between right and left clavicle are significant at 0.001 level.

Table 2
Results of paired *t*-test and percent directional asymmetry in different clavicular features.

Variable	Paired *t*-test			Percentage cases with standardized DA								
	Males	Females	Pooled	Males			Females			Pooled		
				R	L	N	R	L	N	R	L	N
Length (CL)	−12.841**	−7.811**	−15.001**	7.2	91.3	0.5	8.8	83.2	2.9	11.4	86.7	1.9
Circumference (CC)	7.933**	4.136**	8.923**	73.8	18.9	7.2	63.2	19.1	17.6	71.1	19.0	9.9
Weight (WC)	9.979**	6.284**	11.733**	83.1	12.8	4.1	79.4	13.2	7.4	82.5	12.5	4.9
Articular Length (AL)	−11.643**	−6.133**	−13.116**	11.8	85.1	3.1	7.4	83.2	4.4	11.4	85.2	3.4
Robusticity (RI)	11.898**	6.920**	13.725**	83.6	15.9	0.5	73.5	26.5	0	81.7	17.9	0.3
Product-index (PI)	2.598*	0.792	2.696**	62.6	36.9	0.5	58.8	41.2	0	61.6	38.0	0.3
Sternal Diameter (SD)	4.947**	3.374**	5.917**	64.6	35.4	0.0	69.1	30.9	0	66.2	33.8	0
Acromial Diameter (AD)	−1.812	−0.571	−1.883*	37.9	62.1	0.0	44.1	55.9	0	39.2	60.8	0
Middle Diameter (MD)	3.480**	0.008	3.255**	64.1	35.9	0.0	50.0	48.5	1.5	68.4	31.2	0.3
Conoid Diameter (CD)	1.149	0.386	1.203	55.9	44.1	0.0	48.5	51.5	0	53.9	46.0	0
Lateral Angle (LA)	−19.607**	−8.419**	−20.713**	2.6	97.4	0	11.8	88.2	0	2.7	97.3	0
Medial angle (MA)	−18.351**	−9.742**	−20.746**	5.1	94.4	0.5	5.9	94.1	0	5.3	94.3	0.3
Total angle (TA)	−25.481**	−11.448**	−27.295**	1.0	98.9	0	5.9	94.1	0	1.5	98.5	0

* means differences between right and left clavicle are significant at 0.05 level; ** differences between right and left clavicle are significant at 0.001 level.

lengths, diameters and indices considered in the present study. Angles were found good indicators of activity in females.

Rhomboid fossa and perforations were present with greater frequency in male clavicles, particularly in right-side bones. Perforations and nutrient foramen were noticed in more than half of males, though they were absent in females altogether. Female clavicles had either small-sized or medium-sized nutrient foramen and males had large or medium-sized foramen and these size differences of NF significantly discriminated sex of right-side clavicles. Male bones had a well-demarcated and large-sized sub-clavian groove (SCG) whereas females possessed faint or ill-demarcated SCG. Majority of male clavicles were either long and robust or long and smooth, while most female clavicles were found short and smooth. All the non-metric traits considered here revealed significant sex differences for one side (rhomboid fossa end) or both side (perforations, nutrient foramen, type of clavicle) clavicles. Clavicular perforations (present on the postero-superior edge) were present significantly more in male clavicles of both sides. The clavicles belonging to older subjects had a greater frequency of perforations than the younger ones. The younger female had clavicles with significantly greater incidence of small-sized rhomboid fossa. Within same age-group, frequency differences between two sexes were found statistically significant for right clavicle only. Conoid tubercles were found distinctly developed in strenuous workers, i.e., farmers and laborers. Acromial ends were found broad and flat with a strong curvature in subjects engaged in laborious and strenuous physical work. Sub-clavian groove was found deeply grooved and canalized in males than a shallow groove present in females.

Table 3
Results of stepwise multivariate discriminant function analysis of different combinations of clavicular features for sex estimation.

Variables entered	Selected variables (Wilks' Lambda)	CDFC	Eigenvalue/Canonical correlation	SDFC	GC	F to remove	SP	FDFS		Accuracy % from MDFA			
								M	F	M	F	O	SB
Function I	CL-L (0.568)	0.054	0.950	0.472	0.573	27.765	−0.249	1.678	1.559	89.2	89.7	89.4	−0.5
	CC-R (0.590)	0.196	0.698	0.610	−1.644	38.992		2.502	2.068				
	DM-L.522)	0.184		0.224		4.514		1.138	731				
	Constant	−17.315						−183.138	−145.933				
Function II	CL-L (0.594)	0.591	0.916	0.521	0.563	35.751	0.287	17.060	15.773	86.7	89.7	87.5	−3.0
	CC-R (0.683)	2.339	0.691	0.728	−1.615	80.373		27.111	22.018				
	Constant	−17.426						−182.464	−145.655				
Function III	CL-L (0.683)	1.135	0.464	1.00	0.401	121.056	−0.174	19.567	17.809	75.9	83.8	77.9	−7.9
		−16.838	0.563		−1.149			−149.280	−123.768				
Function IV	LA-R (0.988)	0.672	0.121	1.282	−0.204	27.776	0.484	23.863	24.395	61.2	59.5	66.2	1.7
	LA-L (0.908)	−0.276	0.328	−0.543	0.586	4.573		21.548	21.329				
		−55.525						−3230.817	−3274.855				
Function V	MD-R (0.640)	0.243	0.603	0.360	0.457	6.677	−0.198	1.346	0.917	79.0	79.4	79.1	−0.4
	MD-L (0.657)	0.417	0.613	0.507	−1.310	13.700		5.976	5.240				
	SD-L (0.667)	0.151		0.430		18.012		1.860	1.593				
		−10.752						−64.668	−46.426				
Function VI	PI-R (0.568)	0.100	0.854	0.636	0.543	13.638	−0.236	0.834	0.624	83.6	92.6	85.9	−9.0
	PI-L (0.550)	0.063	0.679	0.400	−1.559	5.239		0.685	0.553				
		−8.755						−43.985	−26.648				

CDFC= Canonical discriminant function coefficient; SDFC= Standardized discriminant function coefficient; GC = Group Centroid; SP= Sectioning point; FDFS= Fisher's discriminant scores; M = Male; F= Female; O= Overall accuracy; SB= Sex Bias.

Table 4
Results of multivariate discriminant function analysis of different combinations of clavicular features on basis of physical activity or occupational activity patterns.

Variables entered	Selected variables (Wilks' Lambda)	CDFC	Eigenvalue/Canonical correlation	SDFC	GC	F to remove	SP	FDFS		Accuracy % from MDFA			
								M	F	M	F	O	SB
Function I	CC-L (0.875)	1.590	0.203	0.597	0.513	13.765	0.317	12.036	10.597	71.9	*60.4*	65.4	11.5
	AL-L (0.875)	0.614	0.411	0.595	−0.392	13.671		13.821	13.265				
	Constant	−14.513						−125.387	−112.191				
Function II	CL-L (0.875)	0.571	0.195	0.571	0.503	11.858	0.311	13.429	12.922	72.8	*59.7*	65.4	13.1
	CC-L (0.881)	1.632	0.404	0.613	−0.385	13.767		11.323	9.874				
	Constant	−14.314						−124.299	−111.543				
Function III	AL-L (0.875)	1.031	0.142	1.00	0.430	37.164	0.265	15.712	14.930	68.4	*63.8*	65.8	4.6
	Constant	−14.811	0.353		−0.329			−116.840	−105.567				
Function IV	LA-R (0.984)	0.673	0.252	1.297	−0.571	59.954	−0.067	6.339	7.018	59.6	*76.5*	69.2	−16.9
	MA-R (0.812)	0.206	0.448	0.369	0.437	4.363		18.611	18.819				
	TA-L (0.917)	−0.469		−1.300		38.376		28.450	27.977				
	Constant	12.544						−6086.506	−6073.791				
Function V	MD-R (0.921)	0.443	0.161	0.730	0.457	18.029	0.053	3.585	3.227	70.2	*64.4*	66.9	5.8
	SD-R (0.885)	0.142	0.372	0.474	−0.350	7.288		1.387	1.272				
	Constant	−8.217						−38.462	−31.791				
Function VI	PI-L ()	0.129	0.190	1.00	0.496	49.540	0.058	0.953	0.840	66.7	*62.4*	64.3	4.3
		−6.887	0.399		−0.380			−27.951	−21.868				

CDFC= Canonical discriminant function coefficient; SDFC= Standardized discriminant function coefficient; GC = Group Centroid; SP= Sectioning point; FDFS= Fisher's discriminant scores; M = Male; F= Female; O= Overall accuracy; SB= Sex Bias.

4. Discussions

Human clavicle exhibits higher degree of variability in its shape (Grant, 1971) among individuals with different age, sex, race and occupation affiliations [14,21,22,41,42]. This anatomic variability of clavicle has been widely explored for clinical interventions [21,42,43] and forensic anthropological identifications [12–20,32–34]. Further, the design of fixative devices used to join clavicle fractures depends on the anatomical and biomechanical characteristics of this bone. Ignorance of such variations may clinically restrict the use of pre-designed devices for fixation of collarbone fractures. Clinicians are supposed to have a sound knowledge of pre-fracture anatomical structure and behavior of this bone, though they are not expected to be adept in population-specific variations in these features. Forensically, variations in clavicular osteological traits may form the basis of identification of an unknown skeleton.

Humans differ with regards to their physical forms and features, skeletal maturity and development rates, bodily size and proportions, and the degree of sexual dimorphism [44]. Female skeleton is roughly 20% shorter in its dimensions and proportions than a male skeleton. Thus, male bones are expected to be larger, heavier and more robust than that of females [3,44–46]. Clavicle is no exception to such sexual differences in skeletal features which (variations), in turn, start accumulating early in gestational period (12–14 weeks) aggravating in the adulthood and thereafter [3,12,20]. Statistically significant sexual differences have been noticed in the clavicular dimensions of present study clavicles (except angles) and such differences were in agreement with previous some studies [7,12,16,18–20]. Such differences may be due to some disparities in the skeletal growth and maturation, quantum and duration of adolescent spurts or physical activity between individuals of two sexes. Skeletal maturity is a complex process, influenced by various genetical, endocrinal, activity pattern and nutritional factors [47,48]. The differential intensity and duration of adolescent spurts in two sexes might have further enhanced the quantum of sexual dimorphism in clavicular features. Differences in biomechanical loadings, division of labor and activity patterns may also add up to higher degree of sexual dimorphism in various skeletal districts of human skeleton, including clavicle [49,50]. Males are supposed to do more strenuous and difficult tasks than the females, so female clavicles were found less curved and more angled than their male counterparts.

Among metric traits, the maximum length, mid-clavicular circumference and weight of the clavicle were found bilaterally asymmetric; the length showing left-biased asymmetry [5,21,51], whereas circumference and weight of clavicle exhibited right-biased asymmetry [12,16,33]. All clavicular dimensions of both sexes were compared for equality or inequality in right and left clavicles. Bilateral asymmetry was noticed in almost all the clavicular parameters; angles and lengths of clavicle were more in left-clavicles whereas circumference, indices and diameters were found higher in right-side clavicles (Table 2). The dominant hand side clavicle was found more curved and hence less-angled than the non-dominant hand side clavicle (i.e., left-hand side clavicle). The right clavicle has greater robusticity due to having its greater sagittal diameter and having greater development of most of the ligaments and muscles than the left clavicles. Type of physical work or activity patterns of the deceased might have inculcated right-left differences in different clavicular dimensions. Out of various features, the bilateral asymmetry in clavicular length has been discussed more frequently in literature with several explanations put forth for that. The left human clavicle is generally found longer than the right one due to the differences laid down in early intra-uterine life of an individual [5,21,51]. The left clavicle was longer than the right one in 65% male (4.55 mm) and 67% female (3.14 mm) cases [52]. Cunningham et al. [53], found that 28% clavicles were dimensionally (length-wise) asymmetric (up to 5 mm side differences), but 7% clavicles had clinically significant asymmetry with more than 10 mm side differences that could affect treatment decisions. The varied effects of genetic endowments, mechanical loadings and the impacts of muscular attachments might be responsible for such asymmetries not only in various metric traits of clavicle but also among the non-metric traits of both side human clavicles [5,54–56].

Present results were found in close agreement with previous studies conducted for different population groups worldwide. Such differences between two sexes of both side clavicles might also be because of differences in their modes of life or inherent due to some inherent genetical or environmental (genetical/hormonal/nutritional) factors [5,47,48,54–56]. Modes of life include the conditions and occupations embracing all spheres of human activity and labor. Various studies have confirmed the existence of morphometric or morphoscopical asymmetries in different anthropometric or osteometric measurements, fingerprint patterns, skeletal maturation rates etc. Such asymmetries, probably, develop in early gestational life of an individual when certain physiological, nutritional or disease factors disturb the genetic control of symmetric development of the human body, which may continue even up to adulthood. Besides the environmental, genetical and hormonal factors [57], some mechanical loadings during growth and development also influence the morphological features of human skeleton; however, exact role of external biomechanical factors, intrinsic genetic and endocrinal stimuli on bilateral asymmetry remains still unknown. It is also a well established fact that there occur differences in asymmetric patterns between populations, and even sub-population groups based on factors like economy and their social class [58].

Most people develop a right hand preference for skilled manipulative tasks. However, longer left clavicles in right handed individuals cannot be a reliable criterion for prediction of handedness [59]. Handedness cannot be determined from the observations and measurements of the human skeletal remains with the confidence levels required for forensic purposes [60]. As only right-handed subjects were included in the present study sample, so no correlation could be calculated between clavicular asymmetry and handedness of an individual. The degree of bilateral asymmetry in the human body is found strongly correlated with the type of work a person is doing Bilateral asymmetry is associated with intensive unilateral activity due to development of increased musculature and the resultant increase in bone growth on that particular side. Majority of present study subjects were either agriculturist or farm-laborers engaged in strenuous physical work at their fields or other places of work requiring strenuous physical activities.

Tables 5 and 6 show a comparative analysis of few clavicular variables studied by different workers. Mean dimensions of present study clavicle were found comparatively more than previous Indian studies but significantly less than the clavicles of subjects of other nationalities. All Indian studies were based on clavicles collected from cadavers whereas most international researchers studied clavicles obtained from some historical collections or archaeological samples to estimate sex, age and stature of an individual. Present study clavicles were significantly shorter in dimensions than North Americans and modern Greeks, though they were longer in length and thicker in diameter than all previous Indian studies. It is clear from tables that bone dimensions and hence body-built of individuals from different population groups vary significantly. And this fact should be kept in mind while using clavicle for clinical or forensic anthropological purposes. These divergences in anatomical features may be due to differences in genetical, hormonal or environmental factors affecting growth and activity patterns among individuals of diverse population groups [5,47,48,54–56]. As present study is based on examinations of freshly collected clavicles, post-mortem changes in their dimensions are expected minimal and results may differ appreciably from other studies conducted on dry/archaeological bones [61] (see Table 7).

Table 6 clearly depicts that lateral end of the clavicle is more curved than the medial one and lateral angle showed wide variations among different studies compared here. Male clavicles were found more curved at both the ends than the females. It signifies that males were involved in more strenuous work than females and biomechanical loadings on dominant hand resulted in more curves in that side clavicles and these results were in agreement with previous studies. Nepalese had more curved clavicles than all studies compared here, implying that mountainous lifestyle exerted more stress on their hand during their routine work. Angular differences in the clavicle are important for designing clavicle fixation devices to treat fractures of clavicle. Although usually treated non-operatively by bone settlers or orthopedicians, increased morbidity rates have been recognized with displaced fractures. So, a renewed interest of orthopedicians in fixation of such fractures has stimulated closer scrutiny of clavicular anatomy. Knowledge of clavicular length and its curvature is required for fixing external plates, whereas the diameter and width are needed for planning inter-medullary nailing for fixation of clavicular fractures. Fracture fixation plates need be anatomically contoured and locked.

Indian subjects have greater frequency of rhomboid fossa than the western populations [14,62], probably, because of the fact that Indian people are accustomed to do, relatively, more strenuous and muscular work [39]. Majority of deceased in the present study belonged to laborer or farming community that did strenuous manual/mechanical work during their life time. Parsons [14] had

Table 5
Comparative analyses of clavicular length, circumference and robustness index studied by different workers.

Study	Population and N	Nature of sample	Side	MCL		MCC		RI	
				M	F	M	F	M	F
Jit and Singh [16]	Chandigarh[a] (Indian)	Autopsy	R	145.6 (2.87**)	130.4 (2.98**)	36.2 (6.37**)	29.7 (7.50**)	24.8 (4.63**)	22.8 (4.24**)
			L	147.6 (4.01**)	129.8 (5.57**)	35.7 (1.41)	29.5 (5.42**)	24.2 (1.28)	22.8 (0.07)
Kaur et al. [33]	Patiala (Indian) (100 M, 100 F)	Autopsy	R	146.9 (1.45)	132.6 (2.06*)	36.9 (3.55**)	30.8 (4.31**)	25.3 (2.15*)	23.3 (2.56*)
			L	148.3 (3.22**)	133.9 (3.31**)	36.9 (1.18)	30.7 (1.76)	24.9 (−1.04)	23.0 (0.08)
Kaur et al. [34]	Chandigarh (Indian) (748 M, 252 F)	Autopsy	R	149.4 (−1.23)	134.5 (0.59)	36.5 (7.37**)	31.1 (4.62**)	24.5 (7.52**)	23.3 (3.21**)
			L	151.1 (1.03)	136.2 (1.72)	35.5 (7.67**)	30.9 (1.70)	23.7 (4.24**)	22.7 (1.12)
Patel et al. [65]	Gujarat (Indian) (107 M, 109 F)	Autopsy	R	141.9 (5.79**)	125.9 (7.59**)	37.1 (3.77**)	30.2 (6.31**)	26.2	23.9
			L	142.3 (8.28**)	126.9 (8.61**)	36.4 (2.03*)	30.2 (3.70)	25.6	23.8
McCormick et al. [12]	North American (560 M, 164 F)	Autopsy	R	157.0 (−11.2**)	140.0 (−4.06**)	41.4 (−9.80**)	34.0 (−3.53**)	26.5 (−2.29*)	24.3 (−0.39)
			L	159.0 (−9.66**)	141.0 (−2.38**)	40.7 (−2.5**)	33.6 (−6.3**)	25.7 (−5.51**)	23.9 (−2.84*)
Akhlaghi et al. [18]	Iranian (60 M, 60 F)	Autopsy	M	147.2	130.4	44.07	38.38	29.9	29.4
Papaioannou et al. [19]	Greeks (81 M, 66 F)	Cretan collection	M	153.9	137.0	38.2	32.3	24.8	23.6
Kralik et [7]	Modern Greeks (98 M, 81 F)	Athens collection	R	153.52 (−4.38**)	134.40 (0.59)	41.18 (−5.99**)	34.79 (−5.04**)	26.87 (−2.73**)	25.91 (−4.86**)
			L	155.05 (−2.90*)	136.74 (1.09)	40.37 (−7.48**)	34.31 (−5.83**)	26.09 (−5.34**)	25.22 (−6.12**)
Alicina et al. [20]	Spanish (45 M, 32 F)	Madrid collection	R	155.12 (−5.39**)	132.38 (1.63)	38.00 (1.15)	31.36 (2.52)	–	–
			L	157.02 (−3.07**)	134.81 (2.05*)	37.26 (−0.03)	30.30 (2.94*)	–	–
Present study	Northwest Indian (195 M, 68 F)	Autopsy	R	148.52	135.22	38.52	32.66	25.99	24.20
			L	151.87	138.22	37.24	31.76	24.58	23.03

* means differences between right and left clavicle are significant at 0.05 level; ** differences between right and left clavicle are significant at 0.001 level.
[a] Right Male 120, Right female 51, Left male 116, Left female 61.

Table 6
Comparative analyses of clavicular + angles studied by different workers.

Worker	Side	LA		MA		TA	
		M	F	M	F	M	F
Parsons [14]	R	148.0	150.0	153.0	155.0	300.0	305.0
	L	148.0	151.0	153.0	155.0	301.0	306.0
Terry [41]	R	138.42	144.06	153.52	151.12	292.00	293.88
	L	143.54	145.82	151.58	153.62	294.94	297.0
Terry [41a]	R	139.25	–	153.12	–	293.08	–
	L	142.66	–	151.42	–	293.80	–
Oliver [2]	R	141.8	145.0	150.2	151.0	292.0	296.5
	L	143.0	–	151.4	–	294.4	–
Kaur et al. [34]	R	143.27 ± 10.49	144.65 ± 10.06	150.76 ± 5.47	152.61 ± 5.62	293.08 ± 10.90	297.06 ± 10.61
	L	148.20 ± 8.81	148.73 ± 9.30	150.94 ± 4.71	152.35 ± 5.78	298.04 ± 9.57	301.31 ± 8.95
Haque et al. [36]	R	139.76° ±7.55		150.97° ±6.16		290.73° ±11.14	
	L	141.73° ±8.44		151.50° ±5.67		293.23° ±11.69	
Present study	R	141.1803 ± 1.81	142.56 ± 4.64	151.68 ± 2.90	152.00 ± 3.98	292.86 ± 6.70	294.5641 ± 13.95
	L	143.4606 ± 1.72	143.96 ± 6.49	153.08 ± 2.65	153.37 ± 2.33	296.54 ± 6.46	297.34 ± 11.16

Table 7
Comparative sex-wise percentage frequency distribution of various non-metric traits of clavicle.

Variable	Author	Ethnicity/Region	Male	Female
Rhomboid Fossa	Ray	Australian aborigines	100.0	97.0
	Jit and Kaur [68]	Chandigarh (Indian)	72.0	70.70
	Rogers et al. [39]	Americans	33.5	5.5
	Prado et al. [69]	Brazilian	63.6	2.9
	Present study	Chandigarh (Indian)	92.4	79.4
Perforations	Ray [35]	Australian aborigines	3.1	0.8
	Present study	Chandigarh (Indian)	59.2	32.4
Nutrient foramen	Ray [35]	Australian aborigines	100.0	100.0
	Present study	Chandigarh (Indian)	62.4	36.6
Sub-clavian groove	Ray [35]	Australian aborigines	98.0	90.0
	Present study	Chandigarh (Indian)	96.8	91.2

reported that nutrient foramen was found in about 95% English clavicles, though no differentiation was made between male and female clavicles as regards to occurrence of this foramen. Nutrient foramen (single or multiple) were reported in 100% of Australian aborigine data, whereas, present study found its presence in about 62.4% male and 36.6% female clavicles. Analysis of various non-metric traits along with metric measurements can be a valuable adjunct for forensic identifications as well as for clinical purposes in designing fixation or nailing devices for treatment of clavicle fractures.

Clavicle is commonly found well preserved in most forensic anthropological or bio-archaeological contexts as it is more robust and durable than commonly preferred sex estimation elements like pelvis, skull, etc. [63]. Univariate and multivariate sex estimation accuracy levels are given in Tables 1 and 4 McCormick et al. [12], found product index of the clavicle as best sex estimator like this study as it could correctly classify sex of 85.9% subjects (83.6% males and 92.6% females). Udouka and Nvokediuko [64] found that robustness index could correctly identify sex of 38.2% male and

18.2% female clavicles whereas the product index estimated sex of 34.4% male and 44% female clavicles in a South Nigerian radiographic sample. Robustness index could classify about 64% present study clavicles to their sex category. Patel et al. [65] and Sayee et al. [15] reported correct sex estimation rates of 64% and 85% from MVDFA of length, circumference and weight of the clavicle in a Guajarati and Karnataka population, respectively and this accuracy was about 87.5% for present study subjects from the combination of same measurements. Similarly, Kaur et al. [33] obtained accuracy levels of 86% and 96% for male and female clavicles, respectively for Patiala (India) region using same combination of variables. Papaionnou et al. [19] and Frutos [32] could estimate sex of 94.8% (96.8% male and 91.4% female) and 89.8% Greeks, respectively, from DFA of maximum clavicular length and mid-clavicular circumference. The combined use of length, circumference and robusticity enabled correct sex estimation of 93% European American clavicles from East Tennessee, USA [12]. These differences in bone metrics and sexing accuracy levels may be attributed to actual differences in clavicular metrics, different sample sizes or to the use of different methodologies. Thus, clavicle can be a valuable adjunct for sex estimation of unknown skeletal remains found at crime scene or mass disaster site.

Present study findings are expected to help not only to anatomists, orthopedic surgeons and forensic anthropologists in their professional endeavors, but will also help design more accurate clavicle fixation devices. Designing the fixation devices requires in-depth knowledge of anatomical and physical characteristics of the clavicle [43]. Asymmetric vascularization, lateralized behavior, activity-induced changes or more mechanical loadings of the dominant hand side clavicle, etc., can be the possible explanations for bilateral asymmetry in various clavicular features. Clinicians should be aware of pre-fracture discrepancies in clavicular dimensions for effective operative management of such fractures [53]. As computed tomography imaging has been found an accurate method of describing the anatomy of the clavicle [42,52,66,67], future studies may be carried out using radiographic modalities to further study anatomical features of this bone.

Conflict of interests

There is no conflict of interest with anyone as regards to publication of this manuscript.

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